SECTION 1
Report by the Old Growth Definition Committee

June 2005

Executive Summary

The Old-Growth Definition Committee was chartered by the 2004 Legislature to work with the Washington State Department of Natural Resources (DNR) (Department) to develop a “definition” of old-growth forest that could be used with forest inventory data to provide a map and inventory of old-growth forests on state lands managed by the Department. The three panel of experts (Dr. Jerry Franklin, Dr. Thomas Spies and Dr. Robert Van Pelt) in collaboration with other committee members from Washington State Department of Fish and Wildlife (WDFW) and DNR, are collectively the ‘definition committee.’

The committee’s approach to the task was to use structural features of the forest — such as the occurrence of large, old trees, large snags, and large logs — as the basis for identifying old-growth forests. The structural features that were used had to be limited to those that were part of the regular DNR inventory process. Although stand age is often used to identify old-growth forest it is actually the level of structural development that is critical to ecological function; also, it is easier to objectively characterize stand structure than stand age.

The Committee developed, tested and refined a structural index based on multiple forest stand features to successfully identify old-growth stands on DNR-managed lands on the Westside (west of the crest of the Cascade Range). In using the index to identify old growth stands in a mapping exercise it must be remembered that this is a first approximation. Secondary screening and field review are essential to confirm any stand as old growth. Decreasing index values indicate a decreasing likelihood that a stand is ecologically old growth.

Break points (thresholds) in the indices to define old growth were subjectively selected based on the experience of the ecologists who were familiar with the variation in stand structure and composition in natural Westside forests with various overstory tree ages and disturbance histories. The break point selected (an index score of 60) for defining old growth generally corresponded to stands whose dominant overstory Douglas-firs were >200 years old. Some younger stands had indices that were higher than this threshold and some older stands had indices that were lower. This variation results from differences in site productivity and disturbance history, that is, it is expected that there may be stands that score under 60 on the index that are, in fact, old growth, while others on especially high productivity sites may score over 60 on the index, and not be old growth. One such stand has been identified thus far.

Westside stands that scored >60 on the index were consistently found to be old growth during two field visits. To date, only a single “false” identification (an incorrect characterization of a stand as being old growth) has been identified. Stands that scored between 38 and 59 in the Olympics and 50 and 59 in the Cascades require additional screening to determine their true status. This secondary screening consists of additional analysis of aerial photo and inventory data and, if still unresolved, a field check of the stand. Factors that caused low scores for old-growth stands included their inclusion within map units that were dominantly of another age class, and low densities of structural elements (e.g., large trees) as a result of site conditions.

Use of the structural index to characterize and identify Westside “mature” forests was also explored; the index does appear to have value for identifying mature stands. Most of the existing mature stands are forests of large but not old trees that are of natural origin and that have not been significantly influenced by human activities. These mature forests regenerated naturally following wildfires (e.g., 1902 Yacolt Burn) or windstorms (e.g. 21 Blow) during the 19th and 20th centuries. The significant structural complexity of the mature stands provides significant wildlife and other ecological values, and represents the next generation of old-growth forest. There are some mature stands on DNR-managed lands that originated from regeneration following harvest, and not from natural causes; they are not considered here.

The Committee originally intended to calibrate the structural index for different plant association groups (PAGs), which might have improved the definition. However, sufficient data were not available to develop this refinement and the same structural index was used as a basis for initial screening of all Westside forest types on DNR-managed forest lands. The structural index will be calibrated for secondary screening of PAGs, which have low productivity and smaller tree diameters.

A map of the index classes, based on DNR’s forest inventory units, was developed for Westside DNR-managed lands. Additional field work is expected to determine the status of some stands. The map provides DNR a good first approximation for screening old growth on forested state trust lands. Managers still need to field map and define old growth types through field verification. The current map should provide a first step in the implementation of the Department’s final policy regarding old growth.

The Committee’s efforts to characterize and map old-growth forests east of the Cascade Crest (Eastside) were not successful. Many factors were responsible, including the significant modification of virtually all forests on the ponderosa pine and dry mixed conifer forest sites as a result of past human activity, including fire suppression, logging, and grazing. Historically, Eastside forests were relatively open, low density stands dominated by large old trees; they were maintained in that condition by frequent low intensity fire. Logging over the previous century has removed most of the large old trees and fire suppression and planting have resulted in dense stands dominated by young to mature trees. Such stands are susceptible to stand-replacement fire and do not resemble the historic old-growth forests in either structure or function.

If the legislature wishes DNR to address the old-growth issue on the Eastside, the committee feels that the priority would be to determine sites where the potential exists to restore historic old-growth conditions. These would be sites where populations of large, old trees still exist that could become key structural elements of a restored ponderosa pine forest. Given current conditions on most DNR-managed Eastside forest lands, restoring stands to historic old-growth conditions and subsequently maintaining them would require significant management effort and expense, only some of which is likely to be recovered from sale of wood products. Large, old ponderosa pines are a scarce resource that may merit conservation. Funds are not currently available to pursue assessments of Eastside old-growth forests.

In any case, substantial study is needed of old-growth issues on DNR-managed Eastside forests. Adequate old-growth definitions do not exist for Eastside forest types. Additional field investigations are needed to provide this information as well as to identify sites where the potential may exist for restoring old-growth forest conditions on ponderosa pine and dry mixed conifer sites.

Section 1

Introduction

The Old Growth Definition Committee (OGDC) (Committee) was formed by the Department of Natural Resources (DNR) in response to a legislative charge, per ESHB 2573, section 905, as follows:

> *(1) The Department of Natural Resources shall conduct an inventory on state lands of old growth forest stands as defined by a panel of scientists. The panel of scientists shall include three scientific scholars with well documented expertise in Pacific Northwest forest ecology, one of whom will serve as the chair by consensus of the panel, one representative from the department of natural resources, and one representative from the Washington department of fish and wildlife. The panel shall review the best available scientific information and develop a definition for old growth stands in Washington state. The inventory shall include maps illustrating the distribution of old growth forest stands on state lands, and tables describing the number of acres of stands in each county, the department's administrative unit, and forest type. The maps and tables shall identify both structurally uniform and structurally complex stands. The department of natural resources shall make a report of the inventory to the appropriate committees of the legislature.*
>
> *(2) For the duration of the study, cutting or removing trees and stands 160 years or older is subject to the department publishing notification of proposed cutting or removal of old growth timber.*
>
> *(3) This section expires June 30, 2005.*

The three scientific scholars are academic scientists with extensive experience in the characterization of old-growth forests in the Pacific Northwest (see appendix for short biographies):

> Dr. Jerry F. Franklin, Professor, College of Forest Resources, University of Washington, Seattle, Washington;
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> Dr. Thomas Spies, Project Leader, USDA Forest Service Pacific Northwest Research Station, Corvallis, Oregon; and
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> Dr. Robert Van Pelt, Research Associate, College of Forest Resources, University of Washington, Seattle, Washington.

Also participating were Department of Fish and Wildlife representative Dr. Paula Swedeen, and DNR Representative Sabra Hull. Walt Obermeyer and Steve Curry of DNR provided analysis of DNR's Forest Resources Inventory System (FRIS) data. Dr. Rex Crawford and Dr. Richard Bigley of DNR provided additional valuable ecological consultation and analysis. Rob Pabst of Oregon State University conducted the initial analyses leading to development of the old-growth structural index.

The development of the definitions was a collaborative exercise between the Committee and DNR staff. The definitions were developed and refined in an iterative process that involved three day-long meetings between February and April 2005.

An approach to definition of Westside mature and old-growth forests based on structural complexity was adopted at the initial meeting. This involved the creation of a "structural index" to provide a quantitative comparison of forest stand conditions compared with reference conditions in old forests of Western Washington. This index provides a score for each stand, based on sample statistics from DNR inventory data. This approach underwent testing and development by DNR staff and the Committee during the interim between meetings during which refinements were discussed and adopted. Matching the elements of the structural index to the data available from DNR inventory plots was a critical part of this task; i.e., the definition had to be based upon data that were available from the inventory plots. The resulting index provided a screening tool to use in identifying probable locations of old growth—i.e., stands pre-existing Euro-American settlement in the region and with appropriate levels of structural development.

Two field trips were used to further evaluate the emerging definitions and issues associated with mapping. They proved to be of extraordinary value. The first of these trips was to the Olympic Peninsula and involved Dr. Van Pelt and DNR personnel. The second field trip was to the southern and southeastern Cascade Range and included Drs. Van Pelt, Franklin and Swedeen, and DNR personnel. Key issues in this field trip were structural ratings for mature stands in the Siouxon block and evaluation of stands on the drier eastern slopes of the Cascades.

The definition of old-growth forest conditions for DNR-managed lands and an explanation of how this definition was derived is the subject of this report. This definition was subsequently combined with data from the inventory plots to determine the probable location and acreage of old-growth forests on DNR-managed lands. The purpose of this report is to fulfill the legislative requirement for such an assessment. It is important to note that the task was not simply to define old-growth forest, but to define old-growth forest using attributes that were measured in the DNR inventory plots. This was a challenging task and the reason that the index was used as a screening tool rather than to provide a definitive identification of old-growth forest.

Characteristics of Old-Growth Forests

Forest ecosystems can be characterized by a variety of attributes including composition, function, and structure as well as the age of the dominant trees. **Composition** refers to the diversity of species that are present, such as the number and relative dominance of different tree species. **Function** refers to the "work" or important processes carried out by ecosystems. **Production** — the capture of the sun's energy through the process of photosynthesis and its conversion into energy-rich carbon compounds, including wood — is an important example of such a process or function. **Structure** refers to the diversity of physical features of an ecosystem — such as trees, snags, and logs — and their spatial arrangement.

Most ecological definitions of various stages in forest development, including old growth, focus on the structural attributes of forest. In part, this is because of the difficulty of easily and accurately measuring many of the other attributes. On the other hand, many structural elements are relatively easy to measure and provide surrogates for other ecosystem attributes, such as animal diversity. Structural information is what is collected on forest inventory plots. Finally, structure is what we manipulate during management.

Figure 1. Old-growth forests in the Douglas-fir region are characterized by high levels of structural complexity including a diversity of sizes and conditions of live trees, snags, and logs; this stand is 500 years old, having originated following a major regional fire event around the end of the 15th century (Thornton T. Munger Research Natural Area, Wind River Experimental Forest, southern Washington Cascade Range).

Temperate old-growth forests are characterized by a high diversity of structures, and a high level of heterogeneity in the spatial arrangement of the individual structures (Figure 1). For example, old-growth forests typically incorporate a variety of sizes and conditions of live trees, snags, and logs on the forest floor, including some specimens that are old and/or large for the forest type and site under consideration. Spatial heterogeneity is present vertically — in the form of a vertically continuous but variably dense canopy, and horizontally — apparent in patchiness (including gaps) in stand density.

In contrast with old stands, young even-aged managed forests have very simple structures, with low diversity of sizes and conditions of trees, snags, and down logs and a relatively uniform or homogeneous spatial distribution of these features (Figure 2).

Figure 2. Young, managed forests have low levels of structural diversity and tend to have high densities of uniformly spaced trees.

Mature forests represent a transitional condition between the young and old forest in which stand dynamics are producing a shift from simple to complex structures (Figure 3). An important part of this process is a shift in causes and patterns of mortality. Tree mortality in young stands results primarily from competition and is density dependent — i.e., mortality varies directly with stand density. As stands mature and become old, mortality shifts increasingly toward mortality caused by such agents as bark beetles, root and butt rots, and wind. This mortality is contagious (spatially aggregated), independent of stand density, unpredictable in time and space, and kills large, dominant or co-dominant trees, thereby creating holes or gaps in stands. While such mortality is viewed as undesirable in stands managed for wood production it is essential to the development of functional old-growth stands.

Figure 3. Mature forests, which are generally between 80 and 200 years old, represent transitional conditions between young and old forests; mature stands typically have a significant population of medium- to large-sized dominant trees but typically lack other structural features of old-growth forests, such as a canopy layer that is continuous from ground to top of dominant tree crowns (Douglas-fir dominated mature stand that originated following the Siouxon Burn, southwestern Washington DNR district.

Details of old-growth forest conditions — such as the tree and snag sizes and the speed with which such stands develop — vary dramatically among forest types and with site productivity within a forest type. In general, old-growth conditions develop faster on more productive sites than on less productive sites. For example, structurally complex conditions develop more rapidly in the coastal Sitka spruce–western hemlock forests than in the Cascadian Douglas-fir–western hemlock forests.

Old-growth conditions vary in detail among essentially all forest types in terms of their exact attributes, which is why type-specific definitions are necessary. However, ***old-growth conditions differ profoundly between moist westside forests***, which are characterized by highly infrequent, stand-replacement events, ***and dry eastside forests***, which were characterized by frequent low-severity fire events. Sites that have extreme environmental conditions — i.e., are very wet, very cold, or very infertile — also tend to display distinctive old-growth structures. Examples would be the coastal western redcedar sites (very wet), subalpine mountain hemlock forests (very cold) and some interior lodgepole pine sites (cold, low fertility, and droughty).

Old-growth conditions may develop at very different rates even on sites that are comparable in productivity or environment, depending on the nature of the most recent disturbance and chance. For example, different intensities of wildfire may leave behind very different levels of live trees, snags, and logs (often called "biological legacies") to be incorporated into the regenerating forest. Similarly, re-establishment of the new forest may have occurred either rapidly or slowly, depending upon the availability of tree seed sources.

As noted earlier, patterns of old-growth forest structure differ dramatically between West- and Eastside forests, reflecting the differing disturbance regimes. ***Westside forests are characterized by stand-replacement disturbance or tree reproduction regimes*** that occur at very long intervals; for example, return intervals of wildfire and severe windstorms in western Washington were typically 250 to more than 400 years. ***Dry Eastside forests*** — specifically the ponderosa pine and dry mixed conifer plant associations — ***were subject to frequent, low to moderate severity wildfires that created small openings in the stand where tree reproduction could develop***.

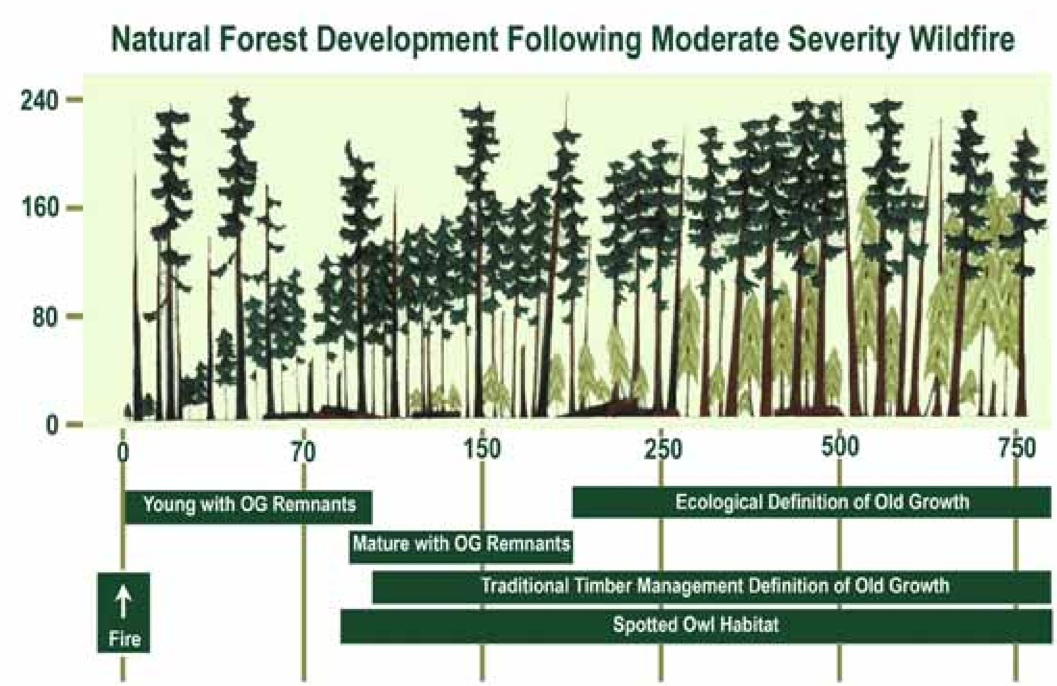

Figure 4. Even-aged stands developed following a major disturbance undergo very long periods of development; on a typical Douglas-fir--western hemlock site the forest typically matures at about 80 to 100 years and begins to strongly exhibit old-growth characteristics (e.g., vertically continuous canopy and gappiness) at around 200 years.

The Westside forests, which originate following stand-replacement fire or windthrow events, undergo several centuries of development before achieving an old-growth state (Franklin et al. 2002) (Figure 4; Figure 5b). Once trees regain dominance on the site following the disturbance, the dense young stands undergo an extensive period (60 to 80 years) of rapid growth and competitive thinning — known variously as the competitive exclusion, stem exclusion, or biomass accumulation stage of stand development. In its second century the young forest matures (Figure 5a). The mature stand gradually takes on more and more of the attributes of old growth, which generally begins to emerge at 175 to 250 years. As noted earlier, mortality shifts from density dependent competitive processes in the young stands to insect, disease, and wind induced mortality in larger trees in the old stands.

Eastside old-growth forests (Ponderosa Pine and Dry Mixed Conifer plant associations) were characterized by chronic disturbances — frequent light to moderate severity wildfire — which maintained them at relatively low density. Structural complexity was present but occurred as a fine-scale, low contrast mosaic of structurally diverse patches (Figure 5c). Logging, fire suppression, grazing, tree planting and other human activities have altered the structure of almost all of these forests. Most commonly they have developed into dense stands capable of supporting stand-replacement fires, which occurred rarely, if at all, under natural conditions.

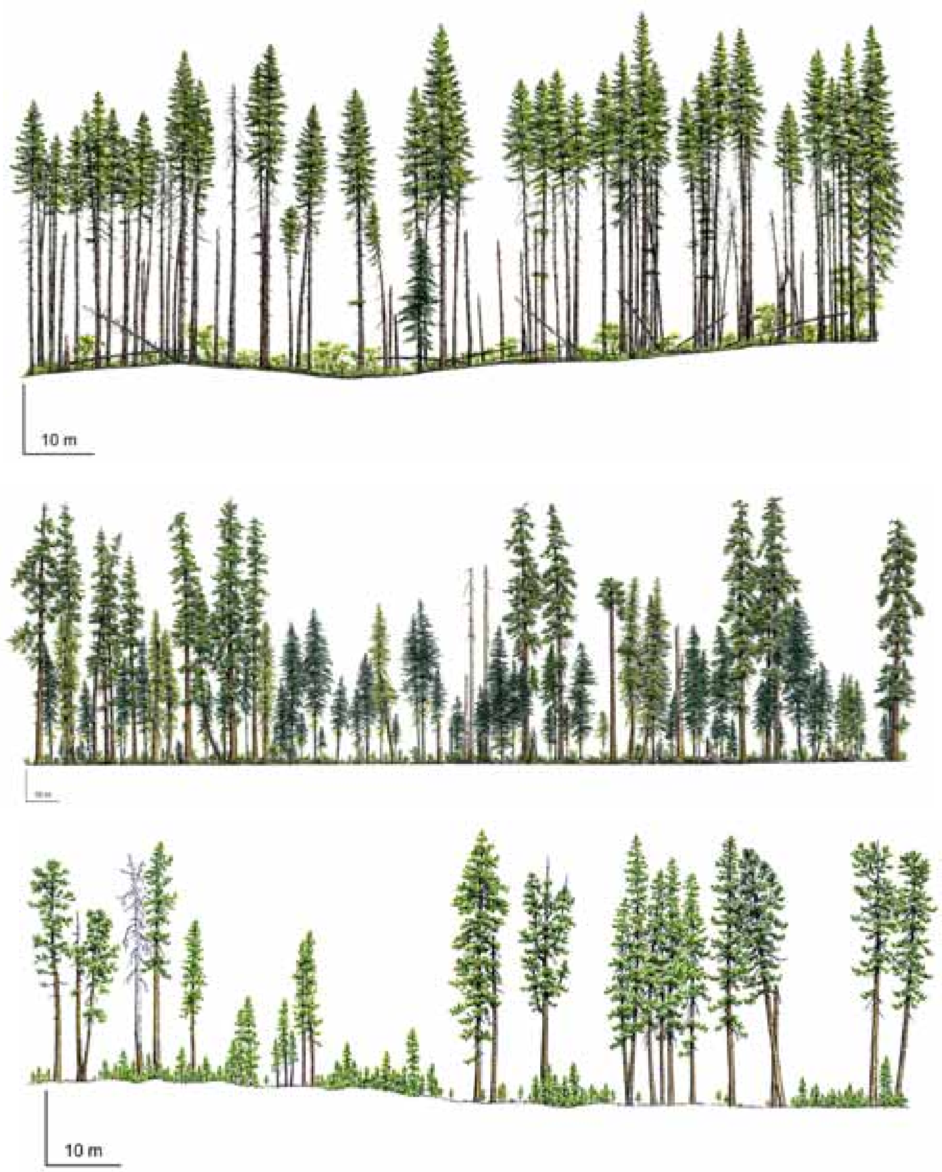

Figure 5. Structural cross sections illustrate the structural heterogeneity of different forests:

(a) maturing even-aged Douglas-fir stand development following a 1902 wildfire in the southern Washington Cascade Range (Martha Creek drainage, Wind River Experimental Forest);

(b) old growth, 650-year-old stand of Douglas-fir, Western redcedar, and western hemlock in the southern Washington Cascade Range (Cedar Flats Research Natural Area, Gifford Pinchot National Forest);

(c) old-growth ponderosa pine stand in southeastern Oregon (Blue Jay Springs Research Natural Area, Winema National Forest).

Premises Underlying Development of DNR Old Growth Definitions

The approach to identifying old-growth stands on DNR-managed land was based on a series of premises. These were that the Committee would:

(1) Attempt to use plant association groups (PAGs) as a basic stratification for the analysis;

(2) Create and utilize structural indices based on multiple stand attributes;

(3) Find that all old growth would have originated prior to European settlement; and

(4) Characterize "mature" as well as old-growth forest many of these are also stands of natural origin (naturally regenerated following wildfire or windstorm), with significant structural complexity, and are generally free of significant human modification.

Use of Plant Association Groups

Since old growth conditions vary with forest types or plant associations, it seemed appropriate to stratify the definitions by plant association or groups of plant associations that have similar old-growth attributes. Had sufficient data existed, we might have opted for definitions for each plant association. However, given the numbers of plots available in the DNR inventory the Committee decided to group the plant associations into larger groupings (PAGs) in developing old-growth definitions. Ultimately a single index was used for all Westside PAGs due to limitations in available data.

The old- growth index is being calibrated for use in secondary screening of old-growth forests belonging to low-productivity PAGs, which will tend to have trees of smaller average diameter.

Use of Structural Indices

Development of old growth involves gradual changes in a variety of structures and functions. Since this evolution generally does not involve abrupt changes the decision as to when the "old-growth stage" begins is rather arbitrary (Hunter and White 1997). The process of defining old growth is further complicated by the fact that not all of the structural and ecological elements change at the same rate and they may not all be present in the same place at the same time. Classifying this continuous and variable process into two classes, old growth and other forests does not do justice to the complexity of forest ecosystems and results in inappropriate classification of stands. A continuous measure of old growth structure, such as an index, offers advantages in assessing the pattern of old growth structure across landscapes. Structure is preferred over age because a single age is difficult to assign to many older forests with trees of many ages. Structure is also more suitable because many ecological processes are related to forest structure and the rate (age) of structural development varies widely with climate and site productivity.

Old-growth indices are metrics constructed by combining structural features of old forests such as large live and dead trees and size diversity. The values of indices range from low to high levels of old-growth structure. While indices rely on several characteristics some, such as large, relatively old trees, are more fundamental to the development of old growth than others. Without large trees in a stand, large dead trees and vertical heterogeneity (e.g., multiple canopy layers) will not readily develop. Consequently, indices based on multiple structural features can be weighted toward large, old trees, which are the source of much, but not all of the structural complexity of old forests.

The value of indices for management lies in the ability to characterize the structural complexity of all stands in a landscape. Managers still need to map and define old growth types through field verification. Index values can be selected to define one or more classes of older forest. The index approach also gives management the flexibility to identify particular structural conditions for specific objectives, such as locating habitat for particular species.

The Committee decided to use the index approach for Westside old growth types because we had relatively well-developed reference data and the forests of these wetter types have undergone little alteration as a result of fire exclusion. Consequently, data from research and inventory plots could be used to develop reference conditions based on a number of important structural attributes including large trees, large snags and logs and variation in tree sizes.

Indices were less suitable for other east side types because less information is available about the structure and dynamics of old growth in these dry fire-prone landscapes. Information is lacking for two reasons. First, fire exclusion and selective logging of large pines has changed the structure of many old-growth stands such that few places exist where fire-dependent old-growth types exist and can be studied. Second, relatively little research has gone into characterizing old growth in these forests so that relevant information is limited. The committee reviewed and field tested the Interim Old Growth Definitions from Region 6 (USFS 1993), and found that they did not accurately reflect old growth conditions on state lands in the areas visited. We currently lack accurate information and time to develop an index for the east side.

In Klickitat County, field-testing of the Westside index resulted in a decision that the index can be successfully used to identify old-growth stands in this Westside-Eastside transitional area.

Development of “old-growthedness” is a gradual process. Experience with earlier efforts to define old growth using an arbitrary set of criteria (e.g. Old Growth Definition Task Group 1986) to categorize a stand as “old growth” or “not old growth” did not work well. Many plots in old-growth stands do not display all of the features that might be used in such a definition, such as densities of large decadent trees, large snags, and large logs. Further — and perhaps most important--such a black-and-white approach does not recognize the continuum of structural or stand development (See, e.g., Franklin and Spies 1991 and Spies and Franklin 1991).

Approach to Eastside Forests

While structural attributes are important in historically fire-frequent forests, such as the ponderosa pine and dry mixed conifer plant associations, a different approach is needed than on Westside and high-elevation Eastside forests. Here the goal is to recognize sites that have the potential for restoration of old-growth conditions based on structure — particularly the presence of large old trees. Once identified such sites would need active management to restore structural conditions to those closer to historic conditions and which would be sustainable under the fire regimes characteristic of these forests.

Identification of Mature Forests of Natural Origin

Characterizations have been provided for mature as well as old-growth forests. Mature stands are not old growth but most do have important attributes from ecological and policy perspectives. Westside forests really have three major developmental stages — Young, Mature, and Old or early, mid, and late successional. Mature forests typically begin to develop around 80 years of age on the Westside and transition to old-growth condition at around 175 to 225 years. The concept or category of “late-successional” was created as part of the Gang of Four process to incorporate all forests over 80 years of age (Scientific Panel for Late Successional Forests 1991). This was done because mature forests are also important in providing habitat for wildlife that specialize in structurally complex forests and their role needed to be reflected in the analysis developed for the United States Congress by the Gang of Four. Of course, mature forests are also the next generation of old-growth forests. DNR has policy both in place and under development to address the conservation of mature forest (HCP IV-180, Draft Policies for Sustainable Forests under development).

The 80-year age parameter selected by the Gang of Four reflected both ecological and historical circumstances. Many of today’s mature stands were created by wildfires in the last half of the19th century and by the wildfires of 1902, including the Yacolt and Siouxon Burns. These stands regenerated themselves naturally. Most have significant biological legacies of residual old trees, large snags, and large down logs, since most were not salvaged (Figure 6a). Hence, they have had little or no human activity.

These mature stands typically have a significant population of moderate- to large-size trees (Figure 6b). There is significant structural complexity in these stands and they are, therefore, important wildlife habitat, such as for nesting, roosting and foraging habitat for northern spotted owls. They are developing into old-growth forest, where replacement old growth is a concern.

Figure 6. Mature stands typically have populations of large-diameter trees and moderate levels of structural complexity due to biological legacies from the preceding stand.

6a. Portion of stand with large-diameter western redcedar snags which remain intact and upright over 100 years following their death (DNR stand that originated following the 1902 Siouxon Burn, southwestern Washington).

6b. Typical stand cross section with some woody debris on the forest floor and a short, soft Douglas-fir snags.

Methodology: An Old Growth Structural Definition for Westside Forest

Development of Indices

The details of index development and its application are provided in Appendix I. Briefly, the Weighted Old Growth Habitat Index (WOGHI), is based on previous published and unpublished work (Spies and Franklin 1988, Franklin and Spies 1991). The WOGHI integrates four key elements of old forests:

1. Large trees (number of trees per hectare > 100 cm dbh)
2. Large snags (number of standing dead trees per hectare > 50 cm dbh and > 15 m tall)
3. Volume of down woody debris (cubic meters per hectare)
4. Tree size diversity

The four elements used in the WOGHI are typically available in forest inventory data. They are also generally correlated with other attributes of complex forest structure such as spatial heterogeneity, broken-topped crowns, and the presence of shade-tolerant tree species. The index can be modified by including age or by weighting the scores toward more distinctive structural elements. For the DNR effort, we did not include age and used a weighting scheme based on the strength of the correlation of the structural feature with time since last disturbance. This gave greater weight to large live trees and tree size diversity in the index. The index values range from 0 to 100 (high levels of old-growth structure).

Break points (thresholds) in the indices to define old growth were subjectively selected based on the experience of the ecologists who were familiar with the variation in stand structure and composition in natural west-side forests of various overstory tree ages and disturbance histories. The break point selected (60) for defining old growth generally corresponded to stands whose dominant overstory Douglas-firs were >200 years old. Some younger stands had indices that were higher than this threshold and some older stands had indices that were lower. This variation results from differences in site productivity and disturbance history, that is, it is expected that there may be stands that score under 60 on the index that are, in fact old growth, while others on especially high productivity sites may score over 60 on the index, and not be old growth; one such stand has been identified thus far.

All of the Westside plant association groups were ultimately screened using the same index. The following descriptions of old growth and mature forests for major PAGs are to provide the legislature with additional general information about these stand conditions.

Old Growth Characterization: Western Hemlock–Douglas-Fir SuperPAG

These forests occur in climatic zones and sites that will succeed to western hemlock dominance over time. Well-developed old growth stands are characterized by the presence of many trees with diameters larger than 100 cm dbh; occurrence of shade tolerant trees in seedling, sapling, mid and upper story canopy layers; occurrence of canopy emergent Douglas-fir trees and large (>50 cm dbh) snags; accumulation of large dead tree boles in various stages of decay; and patchy distribution of canopy gaps and understory vegetation. Shade tolerant associates of Douglas-fir in these stands include western hemlock and western redcedar (See appendix I for more details). Stands with western redcedar are typically found on moist valley bottoms.

Many of the characteristics of old-growth structure begin to emerge between 150 and 250 years. Variation in the rate of development is controlled by site productivity and disturbance history. Many stands experienced fire or large wind disturbances during their development; in some cases these disturbances increase the structural complexity of the stand, while in other cases, they may reduce complexity if they result in the establishment of relatively uniform cohorts of younger trees among the surviving canopy trees. All stands experience small canopy gap disturbances that increase the structural complexity, diversity and productivity of the stands. Stands with extremely old Douglas-firs (>800 years) are often found on colder, lower productivity sites, such as in some of the higher elevations of this zone in Mt. Rainer National Park.

Prior to the old-growth stages, many stands go through a mature phase in which structure and composition becomes much more similar to old growth. Trees become larger (>50 cm), canopies increase in height, gaps form and do not readily close, understories develop and overall animal and plant community composition approaches that of old growth stands. For example, the compositional similarity of plant and animal communities to those in old-growth forests reaches 80 percent or more (Hansen et al. 1991). Mature stages may lack the high accumulations of large standing and fallen trees and the high levels of vertical and horizontal spatial patchiness of old growth. For this reason, the WOGHI values for mature forests typically are lower than for old-growth forests; for example, in the Siouxon block the mature stands developed following the 1902 Yacolt Burn typically had stand values that averaged around 40.

Old Growth Characterization: Sitka Spruce–Western Hemlock PAG

Old-growth Sitka spruce–western hemlock forests can be very similar to old-growth Douglas-fir–western hemlock forests in many structural attributes. Sitka spruce replaces Douglas-fir as the dominant tree in coastal areas of the Pacific Northwest. There are a number of reasons for this change, some of which are related to fire and some to climate. Douglas-fir has thick bark which provides considerable fire tolerance while the thin bark of Sitka spruce provides no protection. The moisture regime of the near-coastal areas also favors the drought-intolerant Sitka spruce.

Sitka spruce is theoretically successional to the very shade tolerant western hemlock in forests where they co-occur. However, Sitka spruce has several strategies for maintaining itself. Sitka spruce is intermediate in shade tolerance and is therefore able to effectively reproduce itself on sites with low- density forest canopies or large canopy gaps — as is often the case in windy coastal areas. The abundant logs created by windthrow are the ideal substrate for spruce seed germination and seedling establishment.

Sitka spruce lives about half as long as Douglas-fir, in part because the tree lacks significant decay-resistant chemicals in the heartwood. After 300 to 400 years, dominant spruces are often highly decayed and collapse as a result. There is no record of a Sitka spruce living to 500 years under the good growing conditions in the Pacific Northwest. However, given the extremely rapid growth rates in coastal areas, stands can achieve the stature of old-growth Douglas-fir-western hemlock forests in about half of the time.

Figure 7. Old-growth stands growing on river floodplains in the Sitka Spruce Zone are the "rainforest" old-growth known for several unique attributes, including immense Sitka spruce dominants, open understories, and large accumulations of mosses and other epiphytes (Queets River drainage, Olympic Peninsula).

The riparian forests growing along large rivers within the range of Sitka spruce are a special case (Figure 7.). These are the world famous ‘rainforests’ of the Olympic Peninsula and Vancouver Island. Trees here reach phenomenal sizes and accumulate incredible masses of epiphytes within their crowns. These riparian forests tend to have very open canopies and park-like understories, the latter conditions largely maintained by large populations of native elk. Several hardwood species, which are absent from most upland forests, are present. Black cottonwood and bigleaf maple attract huge accumulations of epiphytes due to both basic bark chemistry, and their more horizontal canopy structure.

Old Growth Characterization: Pacific Silver Fir–Mountain Hemlock SuperPAG

These forests occur at higher elevations than the western hemlock–Douglas-fir forests. In addition to Pacific silver fir and mountain hemlock, these forests may contain other major conifers including noble fir, western white pine, Douglas-fir, western hemlock, Alaska yellow cedar, western redcedar, and subalpine fir. Old growth conditions generally appear at around 180 to 260 or more years (Fierst et al. 1992). The general characteristics of old growth in these forests are the same as in the western hemlock zone, but the sizes of live and dead trees are typically smaller. Shrub and herb layers may remain sparse in younger forest until they reach 200 or more years when canopy break-up allows more light into the understory.

Old Growth Characterization: Western Redcedar Coastal Plain PAG

Old-growth forests dominated by western redcedar are common on the coastal plain on the west side of the Olympic Peninsula (Figure 8.). Many of these forests are on poorly drained soils with low nutrient levels and often have a stunted swampy physiognomy. Associated tree species include western hemlock, western white pine, lodgepole pine, and red alder. While often exhibiting a short stature, these cedar-dominated forests have complex structures and well-developed understories characterized by such plants as salal, evergreen huckleberry, salmonberry, and deerfern. These sites seldom experienced fire under natural conditions and some areas on the coastal plain on the western Olympic Peninsula probably have not burned for several thousand years.

Figure 8. Old-growth western redcedar-western hemlock stands growing on poorly drained soils on coastal plains are a distinctive and uncommon old-growth forest type. Although tree growth is typically very slow on these swampy, nutrient poor sites, the western redcedar live for many centuries and achieve large dimensions.

Western redcedar and western hemlock have an interesting successional relationship in these stands. For a variety of reasons, including its decay resistant wood and conical stem form, western redcedar has a lifespan that is many times longer than its decay- and windthrow-prone hemlock associate. Over time the proportion of western redcedar in the stand increases, resulting in the physical dominance of these sites by the large old redcedars. The shorter-lived hemlock often remains the most numerous but only in the form of relatively small trees. Wood volumes in these forests can be heavily dominated (up to 80 percent) by the cedar.

Even though most of these sites are low in productivity, the longevity of the cedar often allows them to reach phenomenal sizes. Individual trees in excess of 20 feet in diameter and 15,000 cubic feet of wood are known from these coastal forests. It is difficult to manage these sites for sustained timber production as a result of very slow recovery following logging. Problems include elevated water tables following harvest, excessive slash, poor regeneration and slow growth.

Methodology: Eastside Forest Types

Two approaches were considered regarding ways to characterize or define old-growth conditions on the eastside of the Cascade Range. One of these was to attempt to develop a structural index as was done for the Westside forest types. This was quickly rejected due to lack of data, particularly the availability of reference data from known old-growth forest stands.

The second approach, which was adopted and tested, was to utilize the old growth definitions developed for Eastside forest types by the USDA Forest Service. While the Committee had considerable doubt about their applicability, the definitions were tested during the field trip to the Eastside in May. This made clear that the Forest Service definitions had almost no value in recognizing old-growth conditions on the ground.

Consequently, the Committee was unable to make significant progress on characterizing or defining old-growth forest conditions or on identification of Eastside old-growth stands on DNR-managed lands. Substantial effort will be required to develop the necessary data bases for such definition and identification, including development of reference sites. There are possibilities of collaborations between DNR and federal agencies or academic institutions or both in analysis of old-growth conditions on Eastside DNR-managed lands.

It is probable that there are significant old-growth forest stands on the eastside. Certainly this would include old-growth forest stands at higher elevations, such as in the Engelmann spruce-subalpine fir and lodgepole pine types.

Old-growth forest conditions in the ponderosa pine, pine-oak, and dry mixed conifer types are more problematic. There are some small areas of forest with old-growth-like conditions within these forest types; the Committee noted several of these during the Eastside field trip. However, activities—such as logging (especially of large trees), reforestation, fire suppression and grazing—have grossly modified most of these forests.

The primary goal in old-growth assessment on these PAGs would be to identify sites, which have the potential for restoration to an old-growth condition. These are sites where there is at least a small population of remnant old-growth trees that can provide the structural backbone for a restoration effort (Figure 9.). Necessary restoration activities would be reductions in stand densities and basal areas with special attention to levels of ground and ladder fuels. Prescribed burning may also be needed following initial mechanical treatments of sites selected for restoration.

Restoring old-growth conditions on the ponderosa pine and dry mixed-conifer PAGs would require careful analysis by DNR. Not only would there be substantial investments in identification and treatment of candidate sites but continuing management would be necessary — such as in the form of regular prescribed burns — to maintain the restored forest in a sustainable state.

Figure 9. Eastside forests growing on ponderosa pine and dry mixed-conifer habitat types have been greatly modified by human activities, including fire suppression. Douglas-fir and grand fir have developed high densities in many areas creating the potential for uncharacteristic stand replacement fire. Restoring and maintaining old-growth pine forests on most of these sites would require significant investments. Inventories can identify where the best potential exists for such restoration, which are typically sites where remnant old-growth pines remain, as in the stand illustrated.

Other Important Considerations in Analysis of Old Growth

Individual and Small Patches of Old-Growth Trees

Old-growth elements of large, old live and dead trees can occur as individuals or in small patches. While these elements may not support the same communities and ecological functions as larger stands of old growth, they can provide ecological diversity in younger, less diverse forests and act as refugia for species that typically occur in old-growth stands (Sillett and Goslin 1999). These elements are typically difficult to detect in standard inventories or in aerial photography because they are rare or occur beneath the canopy. Consequently, they cannot be inventoried with standard approaches. Any management practices that address these elements will have to be based on field assessments of individual management units.

Stand size

Spatial scale is important to the definition of old growth. Old growth is a spatial mosaic that emerges at areas that range from 1 to 10 or more acres. The grain of this mosaic varies by the processes that form old growth. For example, the grain is relatively small (<1 acre) where canopy gap dynamics are a major process in the development of old growth. The grain may be larger (1 to 10+ acres) where patchy fires formed old growth. Most research efforts have defined old growth at the scale of about 2 to 20 acres.

Forest inventory data may not match the scale of scientific research on old-growth forests. Forest inventory design — including minimum mapping unit size — varies between forest inventories depending on management objectives and budget availability. For example, inventories often adopt 20 acres as a minimum size of polygon or stand. DNR’s Forest Resource Inventory System (FRIS) mapping unit size ranges from 5 to 300 acres. Where inventory units exceed 20 acres they many contain a mixture of different forest age classes. Consequently, inventories may underestimate the presence of old-growth stands because plots from polygons representing a mixture of stand ages are averaged together and, as an average, may not meet the index threshold for an old-growth stand. Consequently, where large inventory polygons occur, it is advisable to check for inclusions of old-growth forest using the procedures outlined in the following section — first by review of aerial photography and plot data and, in some cases, by actual ground surveys.

Recommendation for Further Work by DNR

Several additional tasks remain with regards to resolution of old-growth forest status on DNR-managed lands.

Westside Forests

The main task on the Westside forests is to complete the secondary screening process for DNR-managed lands. This can probably most readily be accomplished by contracting with a knowledgeable forest scientist to collaborate with DNR staff in office and field checking of remaining unchecked but problematic polygons.

It would also be appropriate for DNR to consider training a set of its resource professionals in characterizing old-growth forest structure and function, to provide staff expertise associated with questions that might arise in implementing an old growth forest policy. In some circumstances field verification or interpretation of the WOGHI may be needed, since it is intended to be a screening tool. Field verification also might be required to address questions related to individual and small patches of forest trees that are not captured by the stand-level inventory that has been conducted as a part of this process.

Eastside Forests

The status of Eastside old-growth forests remains unresolved due to lack of sufficient knowledge regarding existing old-growth forest conditions, including both:

a) the nature of old-growth forests on higher-elevation forest types, such as Engelmann spruce-subalpine fir and lodgepole pine and

b) a policy with regards to old growth on the ponderosa pine and dry mixed-conifer PAGs.

Development of a set of old growth definitions, including collection of data from reference old-growth forest stands, is a relatively straightforward process for the mid- and high-elevation cooler and moister forest types. However, it will involve substantial field and office work. Funds are not currently available to conduct the necessary studies and to create the set of old growth definitions (probably indices), which then could be used to screen DNR-managed lands using FRIS.

Issues related to the ponderosa pine and dry mixed-conifer PAGs are more complex and require some policy decisions and additional field work. First, there are few small fragments of such forest that approximate historical conditions, and these should be identified and conserved.

Most of the ponderosa pine and dry mixed-conifer forests have been highly modified. A management program would be needed to restore stands to a characteristic and sustainable condition and, ultimately, to maintain such forests. This is a policy decision, not a scientific or technical issue.

If a program for restoration of some old-growth forest on ponderosa pine and dry mixed-conifer PAGs were adopted, the most appropriate next step would be an inventory to identify the sites with the greatest potential for restoration. These would be sites where there are residual old-growth ponderosa pine trees still present. Developing an inventory process involving initial screening using FRIS and aerial photography, and a secondary screening based on field – work, would be relatively straightforward.

Currently DNR lacks the financial resources to deal with either development of old growth definitions for moister, cooler Eastside forest types or development of a restoration program for Eastside ponderosa pine forests. Such work might be conducted in collaboration with other agencies, such as the USDA Forest Service, and with state universities. Several agencies, including the Forest Service and several tribes, are heavily engaged in development of restoration and long-term management programs for ponderosa pine and dry mixed-conifer types; some of these efforts could certainly be utilized to jumpstart a program for Eastside forest lands managed by DNR.

Application of the Old Growth Habitat Index in a policy setting

In cases where inventory data seems to contradict conditions on the ground, and following field assessments questions remain as to whether or not the stand qualifies as old growth, the stand could be re-measured as per DNR Forest Resource Inventory methods and the data applied to the index to determine stand classification. It is anticipated that as the index is used and understanding evolves as to how it applies in various stand types, its use may also evolve.

In using the index to identify old-growth stands in a mapping exercise, it must be remembered that this is a first approximation. Secondary screening and field review are essential to confirm any stand as old growth. Decreasing index values indicate a decreasing likelihood that a stand is ecologically old growth or mature forest.

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Appendices

Appendix 1.

Methodology for developing the old growth index — Rob Pabst

Establishing a Reference Condition for Old Growth in Western Washington

A Report to the Washington Department of Natural Resources
Prepared by Rob Pabst, Forest Ecologist

March 18, 2005

Introduction

Characterizing old growth is essential for conservation planning and to help establish goals in forest management. Definitions that simply label forests as old growth or not old growth do not do justice to the diversity of conditions found across the landscape. For example, research on forest structure and dynamics indicates that some elements of old-growth structure can be found in much younger forests (Spies and Franklin 1988), whereas some old-growth forests have been subject to frequent natural disturbances such as partial fires that remove old-growth structures and move stands toward earlier developmental conditions (Goslin 1997).

This report describes a quantitative method for assessing how forest stands compare with reference conditions in old forests of western Washington. The method is called the Old-Growth Habitat Index (OGHI), originally developed by Tom Spies for forests of western Oregon. The OGHI integrates five key elements of old forests:

1. Large trees (number of trees per hectare > 100 cm dbh)
2. Large snags (number of standing dead trees per hectare > 50 cm dbh and > 15 m tall)
3. Volume of down woody debris (cubic meters per hectare)
4. Tree size diversity
5. Stand age (years)

The five elements used in OGHI are typically available in forest inventory data. They are also generally correlated with other attributes of complex forest structure such as spatial heterogeneity, broken-topped crowns, and the presence of shade-tolerant tree species.

Methods

The OGHI for western Washington is based on data (Spies and Franklin, 1991) from 40 unmanaged forest stands in which the canopy-dominant trees ranged in age from 210 to 900 years. Stands were located in the Cascade Range from just north of the Columbia River through Mount Rainier National Park. Specific methods of data collection are reported in Spies and Franklin (1991).

Each of the five elements making up the OGHI is scored on a scale of 0 to 100. Scoring for each element is determined from regression equations (Tables 1 and 2) that describe single- or multi-segmented lines connecting thresholds in the data (Figure 1). The thresholds for each line segment are linked to the statistical distribution of data for that element from the old stands (Figure 2). For comparison, Figure 2 includes data from the unmanaged young (20-79 years) and mature (80-199 years) stands that were sampled as part of the Franklin and Spies (1991) study. The youngest stand in the study was 42 years. There is substantial variability for each element within and between age classes, although it appears that large trees, tree size diversity, and stand age are the elements that most strongly distinguish old stands from unmanaged young and mature stands. These unmanaged stands may or may not be representative of the current population of stands in these age classes on Washington DNR lands.

Trees, snags and logs

For large trees and large snags, an element score of 50 corresponds to the lower-quartile (25th percentile) value from the old stands (Figures 1a and 1b). A score of 75 corresponds to the median value from the old stands, and a score of 100 corresponds to the maximum value. For log volume, a score of 50 corresponds to the minimum value from the old stands, a score of 75 corresponds to the median, and a score of 100 corresponds to the maximum (Figure 1c). Values for tree and snag densities and log volumes were corrected for slope prior to determining the thresholds.

Tree size diversity

Size diversity of trees in a stand is expressed as the Diameter Diversity Index (DDI), a surrogate for tree height diversity. DDI is based on the slope-corrected number of trees per hectare in each of four dbh classes: 5.0-24.9 cm, 25.0-49.9 cm, 50.0-99.9 cm, and > 100.0 cm. Three steps are involved in determining DDI, as shown in the example in Appendix 1. First, a score for each dbh class is determined from a regression equation that describes a straight line running from the origin (0,0) to a maximum score of 1.0 which corresponds to the median density of trees in that dbh class in the old stands (Table 2, Figure 1d). Second, the scores for each class are multiplied by a weighting factor that reflects the relative height of trees in each class. The weights are 1, 2, 3 and 4 for the smallest to largest dbh classes, respectively. In the third step, DDI is calculated as the sum of the weighted scores multiplied by 10. Maximum DDI is 100 [((1.0 x 1) + (1.0 x 2) (1.0 x 3) + (1.0 x 4)) x 10 = 100].

Age of Canopy Dominants

Stand age is defined as the age of the oldest canopy-dominant trees in the stand. In the Spies and Franklin (1991) study, stand ages were determined from counting rings on cut stumps located near the sampled stand or by extracting increment cores at breast height and then adding 5 to 7 years to the ring count to get total age. Age is not a structural feature but is included in the OGHI because some aspects of old-growth biodiversity, such as low-mobility species, require a long time to colonize and accumulate after stand-replacement disturbance. The score for stand age equals 80 at 200 years and 100 at 450 years (Table 1, Figure 1e). This relationship is based on the finding that community similarity between old-growth stands and mature stands was at least 80% for plant species, amphibians and small mammals (Hansen et al. 1991).

OGHI

There are three forms of the Old Growth Habitat Index for western Washington. The standard OGHI is simply the average of the five element scores. A modified OGHI excludes stand age, making the index purely structural. A weighted OGHI is also based on the scores of the four structural elements, with the element scores weighted by a relativized Spearman rank correlation coefficient between each element and stand age (Table 3). Data from stands in all age classes (young, mature, old) were used to calculate the correlations. Associations with age were strongest for large trees and DDI (of which large trees is one component), thus the weighted OGHI emphasizes the density of large trees in a stand. Log volume was moderately correlated with age, taking on a “U-shaped” pattern over time with stands 80 to 320 years of age having relatively low log volumes (Figure 3). The density of large snags was highly variable and of the four structural elements was least correlated with stand age. Snag densities trended toward an inverted U-shaped pattern over time, peaking in stands at about 400 years.

All three forms of the OGHI are scaled from 0 to 100, allowing direct comparisons among them. A sample calculation of each form of OGHI is provided in Appendix 1.

Results

Standard, modified and weighted OGHI’s were calculated for all of the stands sampled in the western Washington Cascades (n=69) (Table 4). For 10 of the 13 young stands, OGHI was highest using the modified formulation (without stand age and unweighted). In comparison, the standard OGHI (with stand age) was highest for the majority of mature (11 of 16) and old (32 of 40) stands.

The standard OGHI for old stands ranged from 49 to 90, with all but two of these stands scoring greater than 60 (Table 4, Figure 4a). None of the mature or young stands exceeded a standard index value of 60, and there was a fair degree of overlap between stands in those age classes. Standard OGHI values for mature stands ranged from about 27 to 59, whereas the scores for young stands ranged from about 25 to 48.

Taking stand age out of the equation with the modified OGHI (Figure 4b) resulted in lower values for all of the old stands (range 41-88), mostly lower values for mature stands (range 21-61), and extended the range of values on the high end for young stands (range 25-54) compared to the standard OGHI (Table 4). When the four structural elements were weighted by their correlation with stand age, OGHI (weighted) was lower still for about half of the old stands (range 37-89) (Table 4, Figure 4c).

The distribution of weighted OGHI scores among young, mature and old stands is shown in Table 5 and Figure 5a. For old stands these scores are separated further into site moisture classes (Figure 5b). The median value for weighted OGHI increased from dry to wet sites, and there was more variability in weighted OGHI on dry sites than on either mesic or wet sites.

Summary

The Old-Growth Habitat Index integrates five elements of stand structure and successional status into a single measure that recognizes the complexity and diversity of forest habitats across a range of ages. Values for OGHI are on a continuum, allowing an evaluation of the degree to which any forest stand compares to old growth. It should be noted that two stands with similar values for OGHI do not necessarily share similar stand structure. For instance, a young stand with a legacy of large snags and high volume of down wood from the previous stand may have a score similar to that from a mature stand with large trees. Conversely, some old stands, particularly those on dry sites, may have an OGHI value similar to a younger stand. The elements comprising OGHI can be examined individually or in different combinations suited to management needs. For example, a modified OGHI excludes age of canopy dominants to emphasize structural attributes only, while the weighted OGHI emphasizes the presence of large trees. The OGHI can also be extended to landscape-level analyses to project forest structure and the extent of old growth across DNR lands in western Washington.

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Table 1 Regression coefficients used to calculate scores for four elements in the Old-Growth Habitat Index for western Washington. Regression equations are of the form y = *m*x + *b* where *y* = score (dependent variable), *x* = element value (independent variable), *m* = slope and *b* = intercept.

Element	Range in element values	Range in scores	Regression coefficients for calculating score	
			Slope	Intercept
Big trees	0 – 16 tph	0 – 50	3.125	0.0
	16 – 28 tph	50 – 75	2.08333	16.66667
	28 – 57 tph	75 – 100	0.86207	50.86207
	≥ 57 tph	100	---	---
Big snags	0 – 5 sph	0 – 50	10.0	0.0
	5 – 9 sph	50 – 75	6.25	18.75
	9 – 20 sph	75 – 100	2.27273	54.54545
	≥ 20 sph	100	---	---
Log volume	0 – 114 m^3/ha	0 – 50	0.4386	0.0
	114 – 383 m^3/ha	50 – 75	0.09294	39.4052
	383 – 1069 m^3/ha	75 – 100	0.03644	61.04227
	≥ 1069 m^3/ha	100	---	---
Stand age	0 – 200 years	0 – 80	0.4	0.0
	200 – 450 years	80 – 100	0.08	64.0
	≥ 450 years	100	---	---

Table 2 Regression coefficients used to calculate scores* for each dbh class in the Diameter Diversity Index (DDI). Regression equations are of the form $y = mx + b$ where y = score, x = trees per hectare in dbh class of interest, m = slope and b = intercept.

Dbh class	Asymptote (median tph in old stands)	Regression coefficients for calculating score		
		Slope	Intercept	Weight
5 – 24.9 cm	295	0.00339	0.0	1
25.0 – 49.9 cm	87	0.01149	0.0	2
50.0 – 99.9 cm	70	0.01429	0.0	3
≥ 100.0 cm	28	0.03571	0.0	4

* For tree densities greater than the median value in each class, the score for that class = 1.0

Table 3. Spearman rank correlation coefficients among the five elements in the OGHI from 69 unmanaged forest stands in the Cascade Range of Western Washington.

Element	Stand age	Big trees	Big snags	Log volume	DDI
Stand age	1.000				
Big trees	0.787	1.000			
Big snags	0.361	0.263	1.000		
Log volume	0.567	0.516	0.358	1.000	
DDI	0.842	0.861	0.315	0.476	1.000

Weighted OGHI based on relativized correlations of the four structural elements with stand age:

Sum of correlations with stand age = 2.557

Weights for OGHI elements:

Big trees: 0.787/2.557 = 0.31
Big snags: 0.361/2.557 = 0.14
Log volume: 0.567/2.557 = 0.22
DDI: 0.842/2.557 = 0.33

Weighted OGHI =
(Big tree score x 0.31) + (Big snag score x 0.14) + (Log volume score x 0.22) + (DDI score x 0.33)

Table 4 Element scores and three forms of OGHI for 69 unmanaged forest stands in the Cascade Range of western Washington. Moisture class codes: D = dry, M = mesic, W = wet.

Locations of a subset of stands (area, stand, age, location):
2-61 (65 yrs): Martha Creek, Wind River Experimental Forest
4-68 (65 yrs): Silver Creek, Mt. Rainier National Park (young)
2-42 (140 yrs): Panther Creek, Wind River Experimental Forest (mature)
2-20 (375 yrs): T.T. Munger Research Natural Area (old)
4-2 (400 yrs): Carbon River, Mt. Rainier National Park (old)
3-2 (500 yrs): Cedar Flats Research Natural Area (old)
4-21 (900 yrs): Chinook Creek, Mt. Rainier National Park (old)

Area	Stand	Age	Age class	Moist class	Elev (m)	Lat	Long	Element Scores				Standard OGHI	Modified OGHI	Weighted OGHI
								Large trees/ha	Large snags/ha	Log volume	DDI			
2	62	42	Y	M	621	45.80	121.97	0.00	62.94	64.50	32.90	35.43	40.09	33.86
3	67	55	Y	M	763	46.43	121.94	0.00	80.55	59.36	35.40	39.46	43.83	36.02
3	68	60	Y	M	655	46.42	121.83	0.00	75.09	66.08	32.10	39.45	43.32	35.64
2	60	65	Y	M	476	45.85	122.98	6.53	0.00	57.43	34.70	24.93	24.67	26.11
2	61	65	Y	M	541	45.78	121.94	0.00	23.40	63.98	49.00	32.48	34.10	33.52
2	64	65	Y	M	472	45.80	121.97	12.97	70.50	83.23	39.50	46.44	51.55	45.24
3	75	65	Y	M	764	46.50	121.69	0.00	34.50	54.15	31.00	29.13	29.91	26.97
4	68	65	Y	M	1168	46.98	121.52	0.00	0.00	72.17	30.00	25.63	25.54	25.78
3	64	70	Y	M	700	46.12	121.99	13.06	51.13	60.01	46.40	39.72	42.65	39.72
3	69	70	Y	M	841	46.43	121.79	0.00	21.80	73.47	47.80	34.21	35.77	34.99
4	60	70	Y	M	850	46.81	121.55	0.00	68.94	85.31	60.00	48.45	53.56	48.22
3	52	75	Y	M	664	46.68	121.61	0.00	31.90	56.49	53.80	34.44	35.55	34.65
3	65	75	Y	M	704	46.64	121.59	0.00	10.70	68.85	32.70	28.45	28.06	27.44

Table 4. (continued) Element scores and three forms of OGHI for 69 unmanaged forest stands in the Cascade Range of western Washington. Moisture class codes: D = dry, M = mesic, W = wet.

Area	Stand	Age	Age class	Moist class	Elev (m)	Lat	Long	Element Scores				Standard OGHI	Modified OGHI	Weighted OGHI
								Large trees/ha	Large snags/ha	Log volume	DDI			
2	65	80	M	M	769	45.93	121.99	13.50	0.00	56.11	48.70	30.06	29.58	32.60
3	42	95	M	M	890	46.69	121.71	7.22	64.75	62.20	55.00	45.43	47.29	43.14
2	41	105	M	M	483	45.88	121.99	21.19	0.00	59.93	63.20	37.26	36.08	40.61
3	48	105	M	M	792	46.67	121.76	0.00	43.40	60.27	60.00	41.13	40.92	39.14
2	54	115	M	D	623	45.87	121.85	0.00	0.00	36.75	52.80	27.11	22.39	25.51
2	50	130	M	M	598	45.87	121.85	8.59	0.00	19.81	56.20	27.32	21.15	25.57
2	51	130	M	D	516	45.85	121.86	15.13	23.90	37.04	58.90	37.39	33.74	35.62
2	53	130	M	D	904	45.83	121.85	0.00	78.57	40.07	50.50	44.23	42.28	36.48
3	40	130	M	M	586	46.07	121.98	0.00	51.00	56.09	60.00	43.82	41.77	39.28
4	41	130	M	M	869	46.75	121.90	13.81	0.00	65.43	62.20	38.69	35.36	39.20
2	40	135	M	M	672	45.85	121.89	32.66	21.10	44.92	57.40	42.01	39.02	41.90
4	10	135	M	W	651	46.73	121.90	54.27	40.10	64.56	83.30	59.25	60.56	64.13
2	42	140	M	M	503	45.09	121.94	12.91	42.60	31.97	49.70	38.63	34.29	33.40
4	40	165	M	M	958	46.75	121.81	0.00	45.40	56.75	60.00	45.63	40.54	38.64
2	99	180	M	M	492	45.88	121.94	0.00	60.31	65.48	60.00	51.56	46.45	42.65
3	46	190	M	M	1124	46.40	121.97	0.00	91.30	56.68	60.00	56.79	51.99	45.05

Table 4. (continued) Element scores and three forms of OGHI for 69 unmanaged forest stands in the Cascade Range of western Washington. Moisture class codes: D = dry, M = mesic, W = wet.

Area	Stand	Age	Age class	Moist class	Elev (m)	Lat	Long	Element Scores				Standard OGHI	Modified OGHI	Weighted OGHI
								Large trees/ha	Large snags/ha	Log volume	DDI			
3	36	210	O	D	1025	46.53	121.95	16.91	36.80	50.22	59.50	48.85	40.86	41.08
4	20	250	O	M	670	46.74	121.55	78.86	77.52	57.72	87.70	77.16	75.45	76.94
4	23	250	O	M	644	46.72	121.56	31.56	82.07	66.08	64.50	65.64	61.05	57.10
4	30	250	O	D	728	46.75	121.55	0.00	59.44	50.01	56.20	49.93	41.41	37.87
3	34	300	O	D	950	46.59	121.56	22.59	75.36	53.09	70.30	61.87	55.34	52.43
4	32	300	O	D	1218	46.94	121.91	75.65	73.75	68.84	89.90	79.23	77.03	78.59
4	19	320	O	M	1072	46.93	121.91	75.28	42.30	61.16	97.80	73.23	69.13	74.99
4	31	350	O	D	987	46.74	121.80	19.09	76.16	79.01	65.90	66.43	60.04	55.71
2	10	375	O	W	295	45.81	121.95	96.14	50.06	76.77	80.30	79.45	75.82	80.20
2	11	375	O	M	378	45.80	121.98	31.63	77.50	76.22	62.10	68.29	61.86	57.92
2	14	375	O	W	517	45.88	122.01	99.75	77.75	88.36	85.20	89.01	87.76	89.36
2	19	375	O	M	549	45.81	121.95	58.10	63.69	80.05	71.20	73.41	68.26	68.04
2	20	375	O	M	420	45.81	121.97	72.48	100.00	63.22	96.70	85.28	83.10	82.29
2	21	375	O	M	452	45.88	121.99	75.34	86.95	78.67	82.60	83.51	80.89	80.10
2	23	375	O	M	630	45.85	121.99	53.40	66.19	67.18	74.60	71.07	65.34	65.22
2	26	375	O	M	511	45.82	122.00	50.44	77.57	71.93	78.90	74.57	69.71	68.36
2	29	375	O	M	540	45.77	121.94	87.25	56.38	70.00	81.60	77.85	73.81	77.27
2	31	375	O	D	710	45.88	122.01	87.19	75.80	68.21	76.40	80.32	76.90	77.86
2	33	375	O	D	915	45.87	122.11	0.00	92.32	76.11	52.60	63.01	55.26	47.03
2	35	375	O	D	689	45.85	121.99	6.31	79.82	70.95	62.90	62.80	54.99	49.50

Table 4. (continued) Element scores and three forms of OGHI for 69 unmanaged forest stands in the Cascade Range of western Washington. Moisture class codes: D = dry, M = mesic, W = wet.

Area	Stand	Age	Age class	Moist class	Elev (m)	Lat	Long	Element Scores				Standard OGHI	Modified OGHI	Weighted OGHI
								Large trees/ha	Large snags/ha	Log volume	DDI			
3	19	400	O	M	875	46.63	121.85	50.75	77.86	79.24	78.80	76.53	71.66	70.07
4	2	400	O	W	622	46.99	122.90	85.34	40.00	78.95	95.80	79.22	75.02	81.04
3	31	440	O	D	891	46.63	121.85	36.91	78.25	62.96	62.30	67.92	60.10	56.81
2	25	450	O	M	975	45.95	121.95	79.59	92.64	77.92	100.00	90.03	87.53	87.78
2	27	450	O	M	626	45.92	121.99	82.09	97.82	66.03	85.00	86.19	82.73	81.72
2	30	450	O	D	706	45.92	121.95	61.33	31.10	65.69	74.90	66.61	58.26	62.54
2	98	450	O	M	776	45.93	121.99	56.75	43.90	82.77	74.70	71.62	64.53	66.60
3	2	500	O	W	404	46.10	122.01	97.42	88.66	88.96	67.90	88.59	85.73	84.59
3	16	500	O	M	506	46.09	121.89	75.20	79.73	87.08	81.60	84.72	80.90	80.56
3	17	500	O	M	529	46.10	122.01	76.86	77.75	72.18	85.30	82.42	78.02	78.74
4	1	500	O	W	617	46.99	122.91	54.21	81.84	100.00	79.20	83.05	78.81	76.40
4	3	500	O	W	658	46.98	122.86	78.49	84.14	92.52	85.50	88.13	85.16	84.68
4	18	550	O	M	1037	46.91	121.53	79.10	50.63	78.72	98.80	81.45	76.81	81.53
3	3	600	O	W	1168	46.69	121.46	78.60	53.19	67.70	90.60	78.02	72.52	76.61
3	32	600	O	D	1049	46.67	121.46	81.22	51.38	68.70	100.00	80.26	75.32	80.49
3	20	650	O	M	797	46.42	121.95	86.18	42.20	79.79	97.50	81.13	76.42	82.35
4	16	700	O	M	988	46.80	121.90	83.94	89.50	77.07	92.10	88.52	85.65	85.90
4	11	730	O	W	727	46.72	121.84	82.03	69.00	96.90	95.50	88.69	85.86	87.92
4	12	730	O	W	680	46.72	121.84	46.91	0.00	87.27	75.60	61.95	52.44	58.69
4	21	900	O	M	820	46.81	121.55	79.66	0.00	68.57	100.00	69.65	62.06	72.78

Table 5. Distribution of the *weighted* OGHI in unmanaged forest stands in the Cascade Range of western Washington. Comparisons are between (a) age classes, and (b) site moisture classes for old stands only.

Age class	Moist. class	N	Quantile value for Weighted OGHI						
			Min	0.10	0.25	0.50	0.75	0.90	Max
Y	All	13	25.78	26.11	27.44	34.65	36.02	45.24	48.22
M	All	16	25.51	25.57	34.51	39.17	42.27	45.05	64.13
O	All	40	37.87	50.97	61.61	76.77	81.29	85.29	89.36
O	Dry	11	37.87	41.08	47.03	55.71	77.86	78.59	80.49
O	Mesic	20	57.10	61.57	68.20	77.10	81.63	84.13	87.78
O	Wet	9	58.69	58.69	76.61	81.04	84.68	89.36	89.39

Figure 1. Line segments used to determine scores for each element in the OGHI for western Washington: a) trees/ha ≥ 100 cm dbh; b) snags/ha ≥ 50 cm dbh and ≥ 15 m tall; c) log volume (m3/ha); d) Diameter Diversity Index (DDI); and e) stand age (years). Thresholds for each segment are based on distribution of data from old stands and/or ecological criteria. Regression coefficients for each segment are shown in Tables 1 and 2. Lines for DDI are for each dbh class:
1: 5.0 – 24.9 cm; 2: 25.0 – 49.9 cm; 3: 50.0 – 99.9 cm; 4 ≥ 100 cm.

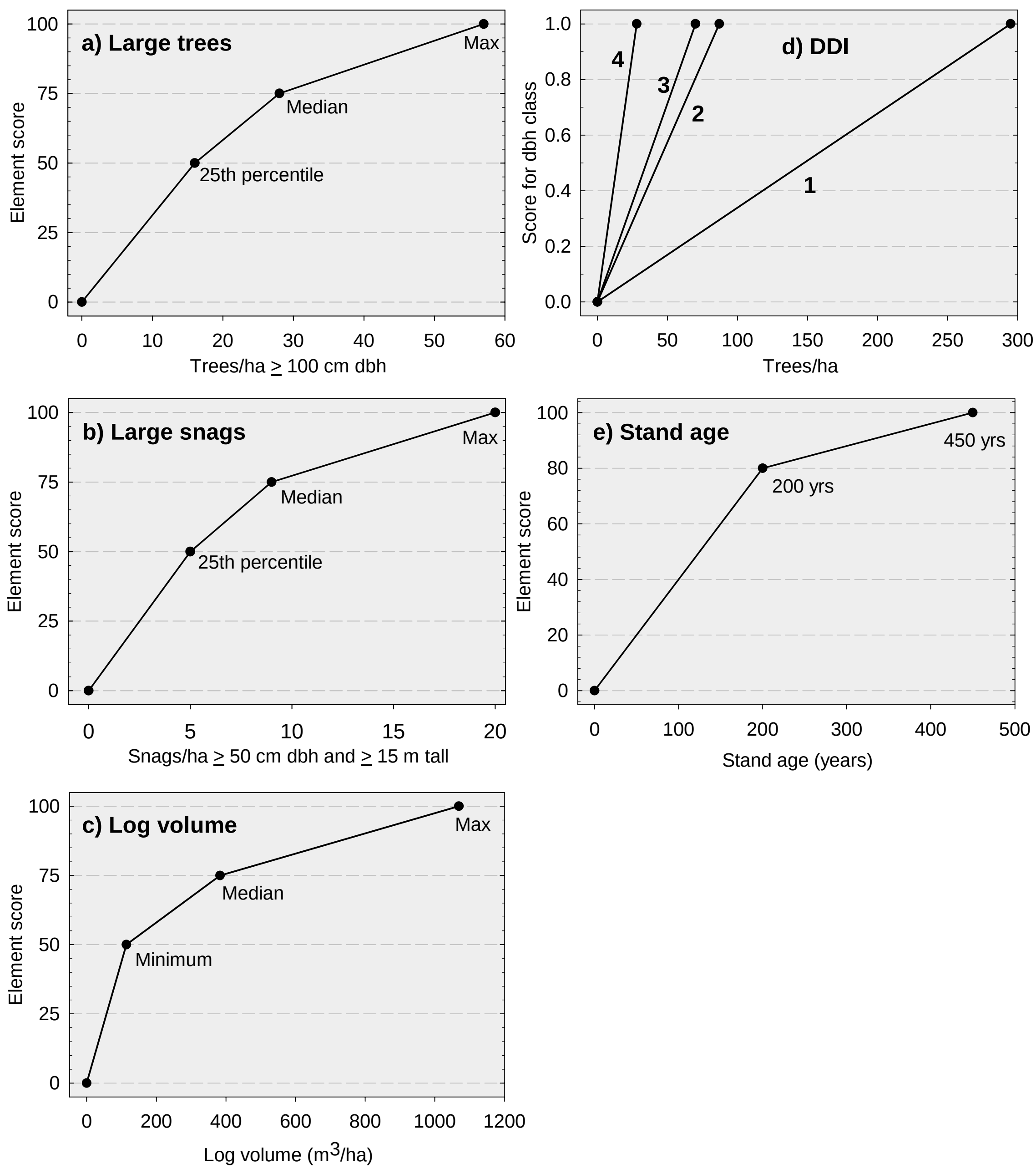


Figure 2. Distribution of data by stand age class from study of unmanaged forest stands in the Cascade Range of western Washington (Spies and Franklin 1991). Each of the five elements in the OGHI is shown: a) trees/ha $\geq$ 100 cm dbh; b) snags/ha $\geq$ 50 cm dbh and $\geq$ 15 m tall; c) log volume (m3/ha); d) Diameter Diversity Index (DDI); and e) stand age (years). In the box-and-whisker plots, boundary of the box closest to zero is the 25th percentile, the line within the box is the median, and the boundary of the box farthest from zero is the 75th percentile. Whiskers (error bars) above and below the box are the 90th and 10th percentiles, with circles representing data points outside those bounds.

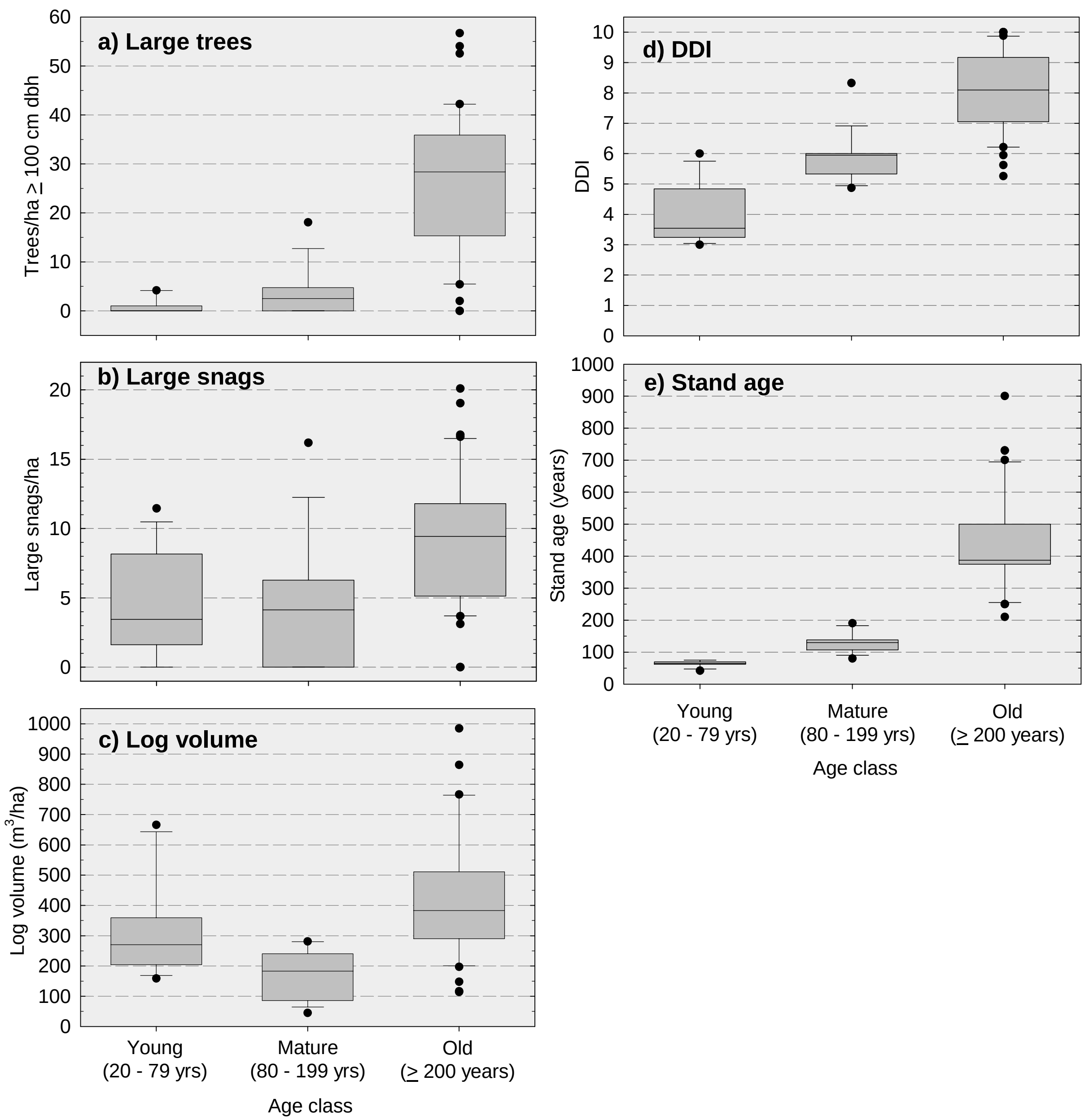


Figure 3. Scatterplots between the four structural elements in the OGHI and stand age for 69 unmanaged stands in forests of the Cascade Range of western Washington.

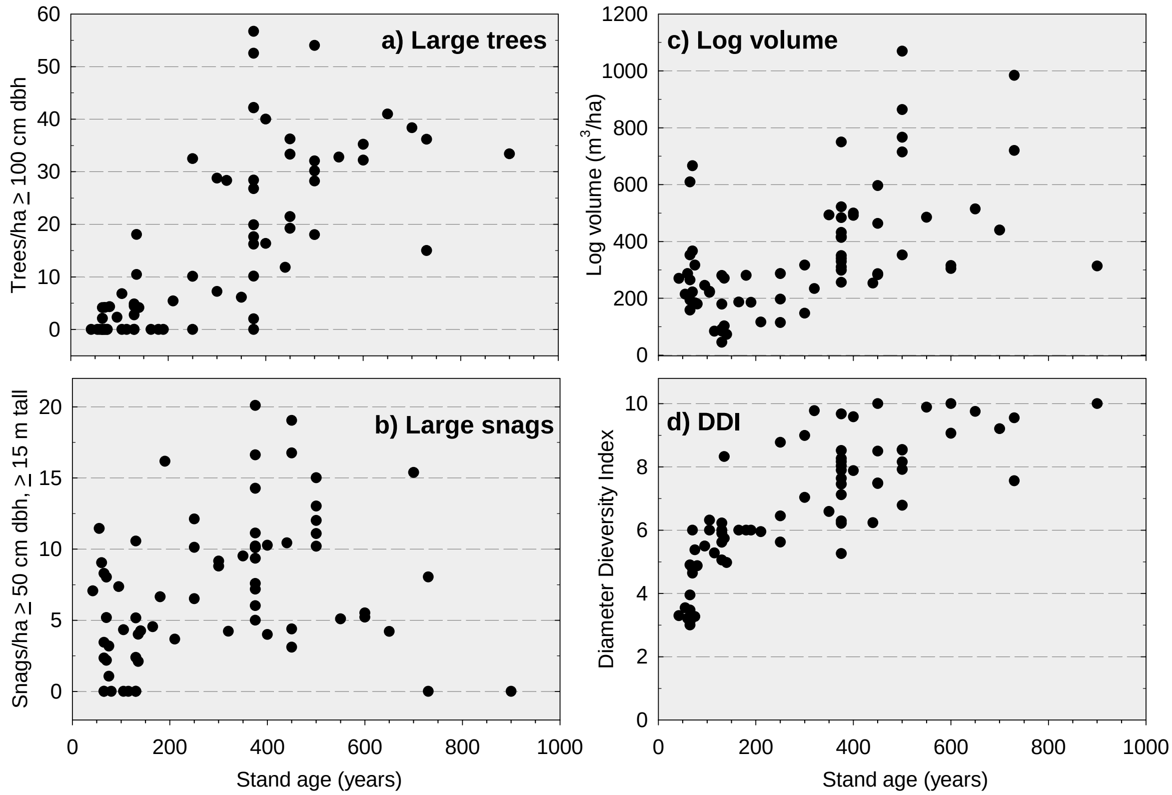


Figure 4. Three versions of the Old-Growth Habitat Index (OGHI) for unmanaged stands in the Cascade Range of western Washington: a) standard, b) modified, and c) weighted.

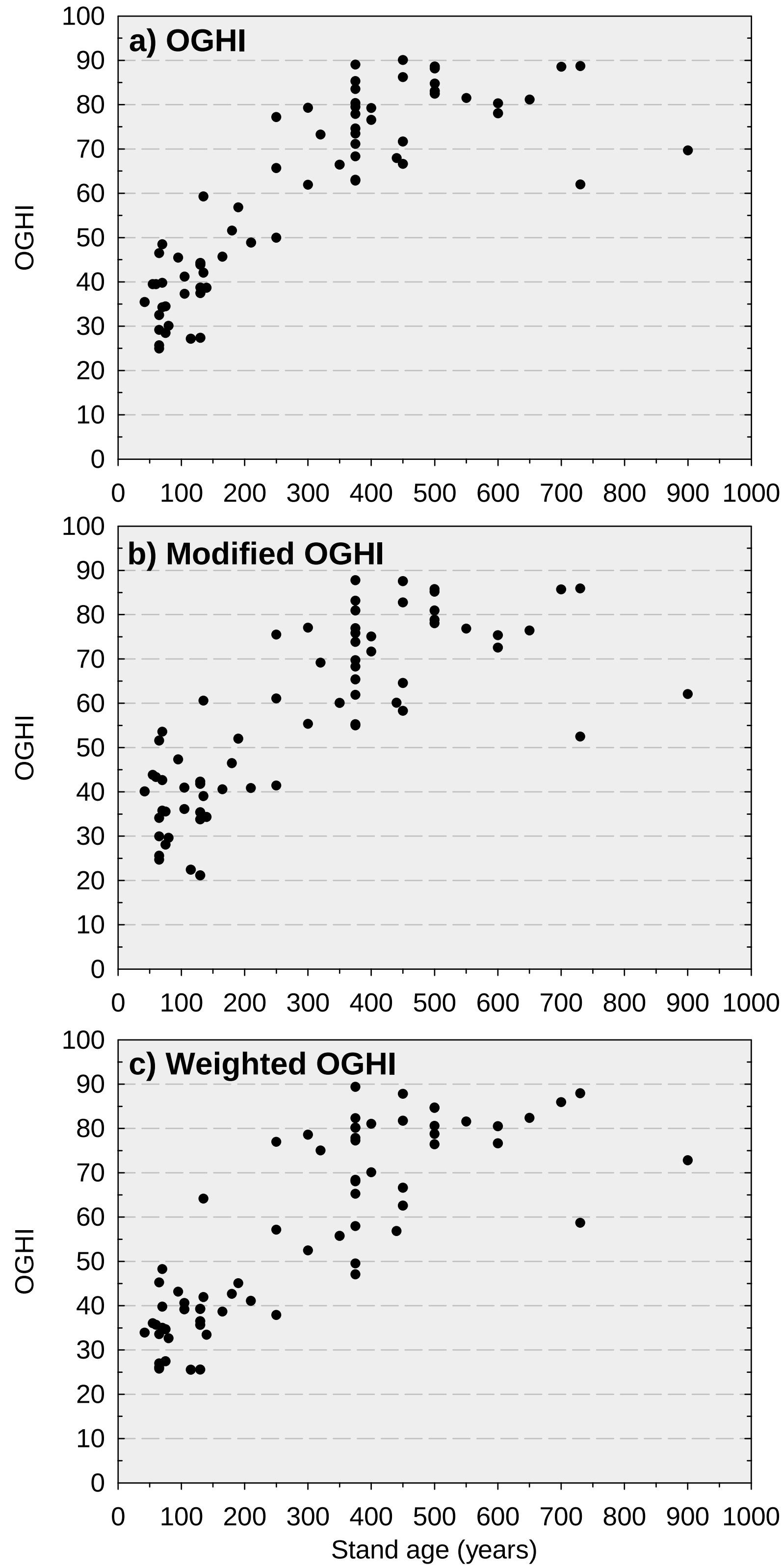
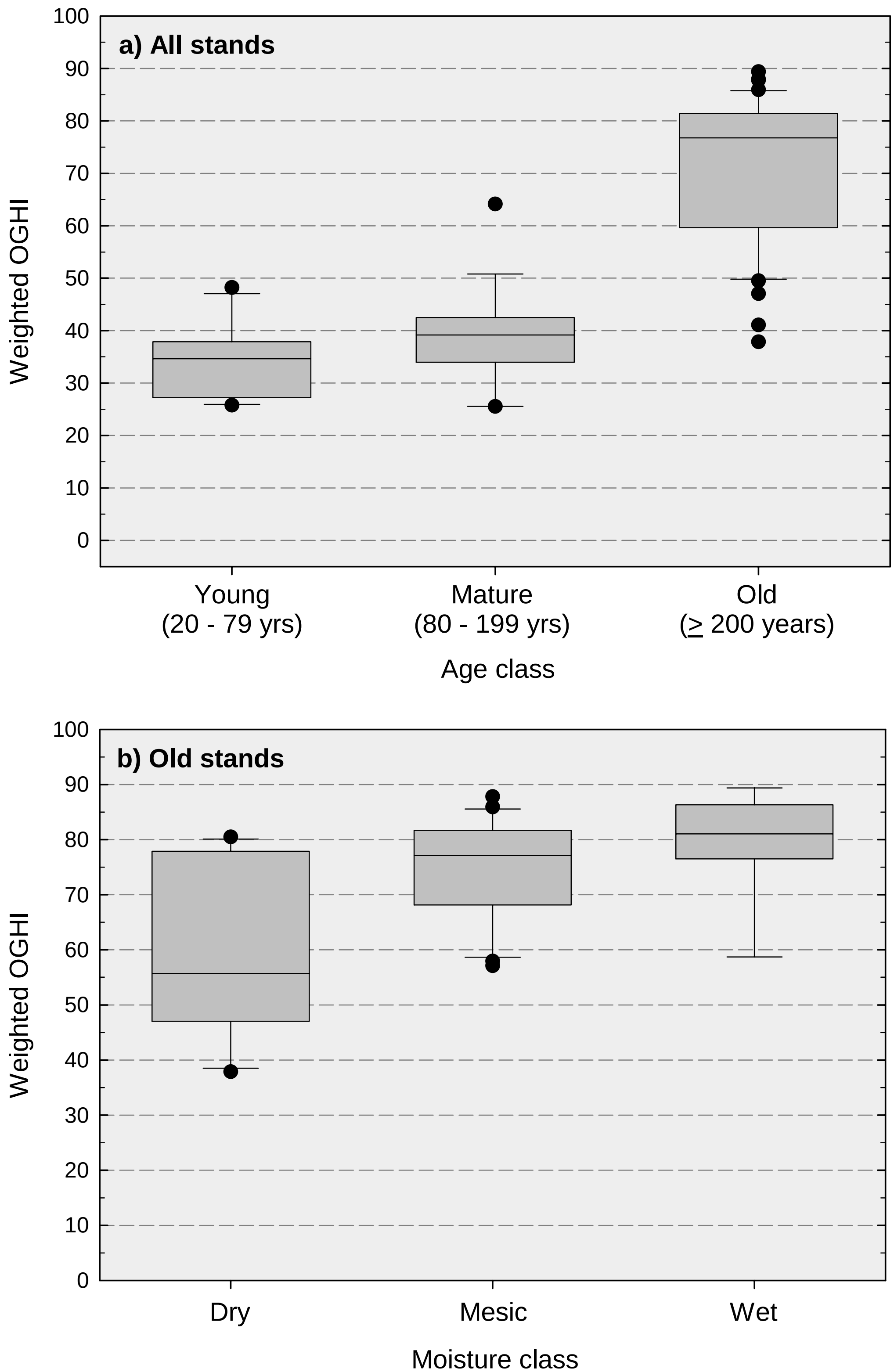


Figure 5. Box-and-whisker plots of weighted OGHI for a) all stands by age class, and b) old stands by moisture class.



Appendix 1. Example of calculating the Old-Growth Habitat Index for western Washington

Stand data

Element 1: slope-corrected number of trees $\geq$ 100 cm dbh = 2.3 trees/hectare
(Note: fraction a result of averaging data from subplots and applying a slope-correction factor.)
Element 2: slope-corrected number of snags $\geq$ 50 cm dbh and $\geq$ 15 m tall = 7.4 snags/hectare
Element 3: slope-corrected log volume = 245.2 m^3/hectare
Element 4: Diameter Diversity Index = 55.0 (derivation shown below)
Element 5: total stand age = 95 years

Calculation of Diameter Diversity Index (DDI) (use coefficients from Table 2)

Slope-corrected tree densities by dbh class (Note that trees < 5.0 cm dbh are not included):

Class 1 (5.0 – 24.9 cm):	725.4 trees/hectare
Class 2 (25.0 – 49.9 cm):	292.1 trees/hectare
Class 3 (50.0 – 99.9 cm):	50.5 trees/hectare
Class 4 ($\geq$ 100 cm):	2.3 trees/hectare

Score for Class 1 = 1.0 (density exceeds median from old stands) x weighting factor of 1 = 1.0
Score for Class 2 = 1.0 (density exceeds median from old stands) x weighting factor of 2 = 2.0
Score for Class 3 = 0.01429 x 50.5 = 0.72 x weighting factor of 3 = 2.16
Score for Class 4 = 0.03571 x   2.3 = 0.08 x weighting factor of 4 = 0.33

DDI = (1.0 + 2.0 + 2.16 + 0.33) x 10 = 54.9

Calculation of other element scores (use coefficients from Table 1)

Score for big trees: 3.125 x 2.3 = 7.2
Score for big snags: (6.25 x 7.4) + 18.75 = 65.0
Score for log volume: (0.09294 x 245.2) + 39.4052 = 62.2
Score for stand age: 0.4 x 95 = 38.0

Calculation of OGHI (average of element scores)

Standard OGHI = (7.2 + 65.0 + 62.2 + 54.9 + 38.0)/5 = 227.3/5 = 45.5

Modified OGHI (without stand age) = (7.2 + 65.0 + 62.2 + 54.9)/4 = 189.3/4 = 47.3

Weighted OGHI* = (7.2 x 0.31) + (65.0 x 0.14) + (62.2 x 0.22) + (54.9 x 0.33) = 189.3/4 = 43.

Appendix 2.

Biographical briefs on panel members

Jerry F. Franklin is Professor of Ecosystem Analysis in the College of Forest Resources, University of Washington, in Seattle. Previously, he has been Chief Plant Ecologist, USDA Forest Service, Corvallis, Oregon, and Professor of Forest Science and Botany at Oregon State University. He also served as Director of the Ecosystem Studies Program of the National Science Foundation in Washington, D.C. He holds B.S. and M.S. degrees in Forest Management from Oregon State University, and a Ph.D. in Botany and Soils from Washington State University, Pullman. He is one of the pioneers of forest ecosystem research, with specializations in structure and function of natural forest ecosystems; successional processes following catastrophic disturbances; effects of changing environmental conditions on forest processes; application of ecological principles to the management of natural resources; and theory and practical applications of landscape ecology. He is a past president of the Ecological Society of America, was a panelist on the White House Forest Conference in 1993, and has served on the Board of Governors of the Nature Conservancy. He has worked on scientific policy analyses for Congress, the federal government, state governments, and for British Columbia. He holds the Barrington Moore Award for outstanding achievement in forest research from the Society of American Foresters, as well as numerous other awards. His research is documented in nearly 300 publications. He is currently extensively involved as a consultant and land steward for sustainable forestry projects in southern Chile and Argentina.

Thomas Spies is a Research Ecologist at the USDA Forest Service, Pacific Northwest Research Station, in Corvallis, Oregon, where he is Committee leader of the Landscapes and Ecosystems Team. He is also a courtesy professor in the Department of Forest Science in the College of Forestry at Oregon State University. He received his Ph.D. in from the School of Natural Resources at the University of Michigan in 1983. He has been a research fellow at Forestry Research Station in Baden-Wurttemberg, Germany and at Harvard Forest in Massachusetts. He was a member of the Forest Ecosystem Management Team that developed the Northwest Forest Plan. His research interests are broad and include stand dynamics, old-growth forest ecology and conservation, wildlife habitat relationships, remote sensing applications, and landscape ecology. He is currently co-leader of the Coastal Landscape Analysis and Modeling Study (CLAMS), an interdisciplinary project to evaluate ecological and socio-economic consequences of forest policies.

Robert Van Pelt is currently on the research faculty at the University of Washington in Seattle where he is engaged in canopy research in *Pseudotsuga*, *Sequoia*, and *Picea* forests. He gives occasional lectures and leads field trips for the University, and teaches several field classes on Pacific Northwest old-growth forests and Northwest canopy ecology.

Bob received his MS in 1991 and PhD in 1995 from the University of Washington. His main research interests are old-growth ecology, canopy structure and its control of the understory environment, spatial patterns in old-growth forests, and tree plant geography.